PHYSICAL
SCI.LIB

TN
24
C3
A33
NO.131

ECENCY AND CHARACTER OF FAULTING ALONG THE ELSINORE FAULT ZONE IN SOUTHERN RIVERSIDE COUNTY, CALIFORNIA

1977

CALIFORNIA DIVISION OF MINES AND GEOLOGY

Research sponsored in part by the U.S. Geological Survey,
Department of the Interior, under U.S.G.S. Grants No. 14-08-0001-G-133 and -263.

SPECIAL REPORT 131

UNIVERSITY OF CALIFORNIA
DAVIS
FEB 1 4 1978
CALIF.
~~U. S.~~ DEPOS.
GOVT. DOCS. - LIBRAR

U.C.D. LIBR

THE GREAT SEAL OF THE STATE OF CALIFORNIA
EUREKA

Special Report 131

RECENCY AND CHARACTER OF FAULTING ALONG THE ELSINORE FAULT ZONE IN SOUTHERN RIVERSIDE COUNTY, CALIFORNIA

By

Michael P. Kennedy

1977

Research sponsored in part by the U.S. Geological Survey, Department of the Interior, under U.S.G.S. Grants Nos. 14–08–0001–G–133 and –263. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
1416 Ninth Street, Room 1341
Sacramento CA 95814

STATE OF CALIFORNIA
DMUND G. BROWN JR.
GOVERNOR

THE RESOURCES AGENCY
HUEY D. JOHNSON
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
PRISCILLA C. GREW
DIRECTOR

DIVISION OF MINES AND GEOLOGY
THOMAS E. GAY JR.
STATE GEOLOGIST

UCD LIBRARY

Digitized by the Internet Archive
in 2012 with funding from
University of California, Davis Libraries

http://archive.org/details/recencycharacter131kenn

TABLE OF CONTENTS

ABSTRACT iv
INTRODUCTION 1
TECTONIC AND GEOLOGIC SETTING 1
  General Statement 1
  Subjacent Rocks 3
  Superjacent Rocks 3
FAULTING 8
LIQUEFACTION POTENTIAL 10
SUMMARY 11
CONCLUSION 11
REFERENCES CITED 11

ILLUSTRATIONS

Plate 1. Geologic map of the Elsinore fault zone, Southern Riverside County, California .... in pocket

Photo 1. Willard fault zone between Lake Elsinore and the Agua Tibia Mountains 3

Photo 2. Wildomar fault zone near Rancho California 6

Photo 3. Wolf Valley fault zone 10

Figure 1. Index map of the area of Plate 1 2

Figure 2. Index map showing locations of rocks dated isotopically by K/Ar analyses and a list of each experimental age 4

Figure 3. Index map and columnar sections showing fossil localities 5

Figure 4. Diagrammatic relationship between the Pauba Formation, an unnamed sandstone and conglomerate formation, the Temecula Arkose, and the rocks of the Mesozoic basement complex 5

Figure 5. Index map showing base of tectonically deformed late Pleistocene terrace deposits 7

Figure 6. Diagrammatic structure section across Murrieta Valley 10

Table 1. Landslide deposits shown on Plate 1 7

Table 2. Selected exploratory and water wells 8

Table 3. Faulted rock units 9

ABSTRACT

The Elsinore fault zone between Wildomar and upper Wolf Valley, Riverside County, California, forms a pronounced structural and topographic boundary between the Santa Ana Mountains and the Perris Block, and consists of a geometrically complex group of faults that have both lateral and vertical slip components. These faults constitute two major zones, the Willard fault zone on the west and the Wildomar fault zone on the east, that bound an asymmetrical northwest–striking, 1–2 km (kilometer) wide, alluvium–filled trough (the Elsinore trough). The center of the trough coincides approximately with the modern drainage of Murrieta, Temecula, and Wolf Valleys. More than 1200 m (meters) of Late Cenozoic sediment underlie the valley floor along the eastern side of the trough near Murrieta. Quaternary age right–lateral strike–slip separations are greater than 5 km along the Wildomar fault zone and less than a few hundred meters along the Willard fault zone. The Willard fault zone, in contrast to the Wildomar fault zone, is composed mostly of nearly vertical dip–slip and moderately low–angle, west–dipping thrust faults suggesting crustal shortening between the Elsinore trough and the Santa Ana Mountains.

Microseismic data indicate that the Elsinore fault zone is moderately active along its southernmost part near Mexico and that this activity decreases to the north in southern Riverside County. In addition, only one felt earthquake greater than Richter magnitude 4.5 has occurred in historic time along this segment of the fault zone. Only sixty earthquakes (M2–M4) occurred here between 1932 and 1972.

Displaced Holocene alluvium, laterally offset drainages, closed depressions, and faceted topography mark many of the most recent traces of faults here. They represent the best supporting data for Holocene activity on this segment of the zone.

In the event of a larger earthquake along this segment of the Elsinore fault zone, poorly consolidated, locally water–saturated sediments in the valley floor could liquefy and cause lateral spreading. The potential for local liquefaction is moderately high and should be considered a primary seismic hazard in Temecula, Pauba, and Wolf Valleys.

RECENCY AND CHARACTER OF FAULTING ALONG THE ELSINORE FAULT ZONE IN SOUTHERN RIVERSIDE COUNTY, CALIFORNIA

By MICHAEL P. KENNEDY*

INTRODUCTION

This report presents the findings of a two–year evaluation of the recency and character of faulting along the Elsinore fault zone between the town of Wildomar (lat. 33°36′N., long. 117°16′W.) and upper Wolf Valley (lat. 33°25′N., long. 117°03′W.) in southern Riverside County, California (figure 1).

The purpose of this study was to gather geologic data necessary to assign a maximum and minimum age to, and to assess the over–all length of individual faults within, this segment of the Elsinore fault zone. Detailed geologic mapping of the area (plate 1) was required to establish a meaningful age and spatial relationship between the rock stratigraphic record and faults displacing it.

Data from four geophysical investigations have been useful in understanding the regional tectonics. The geophysical studies are: (1) an aeromagnetic survey of the Agua Tibia Primitive Area (Irwin and Green, 1970); (2) a microseismic study of the Elsinore fault zone (Langenkamp and Combs, 1974); (3) a gravity survey of the Temecula area (Moyle and Downing, 1975); and (4) a magnetic survey consisting of a straight–line traverse across the Wildomar and Willard fault zones (R.H. Chapman, written communication).

The magnetic survey and an assessment of the gravity data (Moyle and Downing, 1975; Shawn Biehler, written communications) were made by Rodger H. Chapman, geophysicist, California Division of Mines and Geology, during this investigation. Several faults are indicated by the gravity data and are shown by a special symbol on plate 1. The magnetic survey was made with a Geometrics Model 816 total–intensity magnetometer and consisted of twelve traverses having a combined length of over 19 km and station intervals of 30.5 m. The survey was made in the hope that individual faults now thought to be covered by modern slope–wash debris could be detected by measuring a difference in the magnetic susceptibility that rocks in the area are known to have. We were unable to measure such differences, however, either because faults do not exist in those areas studied or, more likely, because the difference in magnetic susceptibility between those rock units faulted is too small to adequately measure. No anomalies were detected that could be absolutely attributed to faulting, and consequently these data are not provided herein. These records are available for review in the Sacramento District Office of the California Division of Mines and Geology.

The faults shown on plate 1 are indicated by a solid line where their existence is known, based on geologic relationships, and by a dashed line where their existence is inferred, based on geomorphic evidence noted on aerial photographs. Most of the faults shown were first observed on low– and intermediate–sun–angle stereo and high–altitude oblique photographs. These include 1953 U.S. Department of Agriculture (scale 1:24,000), 1967 U.S. Geological Survey (scale 1:15,000), 1975 U.S. Geological Survey (scale 1:24,000), and 1967 U.S. Air Force photographs.

Previous investigations that have been valuable in this study include an analysis of the geology of a portion of the Elsinore fault zone in Riverside County by J.F. Mann (1955), a discussion of the Pliocene–Pleistocene history of the Perris Block by A.O. Woodford and others (1971), a report and map discussing the recency of faulting in southern California by J.I. Ziony and others (1974), and the Santa Ana sheet of the State Geologic Map by T.H. Rogers (1965). In addition, work in progress on the recency of faulting along the Elsinore fault zone between Corona and Wildomar by F.H. Weber, Jr., of the California Division of Mines and Geology and between the international boundary with Mexico and the Riverside–San Diego County boundary by M.M. Clark of the U.S. Geological Survey have been of special help in evaluating this area.

I appreciate the valuable advice received in the field and in the laboratory from Cliffton H. Gray, Jr., F. Harold Weber, Jr., James E. Kahle, and Paul K. Morton of the California Division of Mines and Geology; from George W. Moore, Douglas M. Morton, and Malcolm M. Clark of the U.S. Geological Survey; from Michael A. Murphy of the University of California, Riverside; and from D. Krummenacher of San Diego State University.

This study was supported by U.S. Geological Survey Grants Nos. 14–08–0001–G–133 and –263. Field work was completed in May 1976.

TECTONIC AND GEOLOGIC SETTING

General Statement

The Elsinore fault zone is a major northwest–striking group of faults of the San Andreas fault system (Biehler and others, 1964) that extends for more than 200 km from Corona on the north to the international boundary with Mexico and beyond on the south (figure 1). Individual faults in the zone are generally

---

*Geologist, California Division of Mines and Geology.

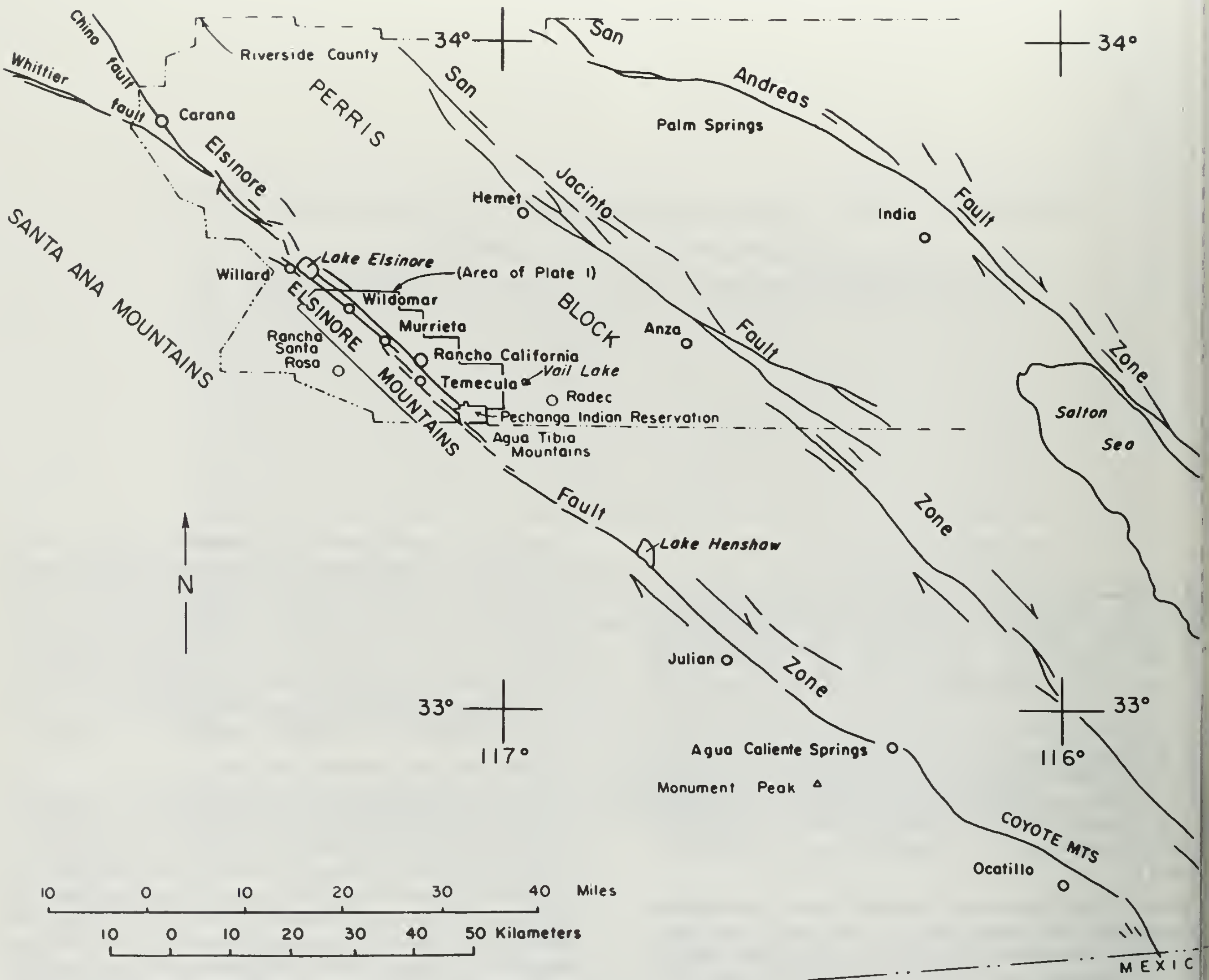


Figure 1. Index map showing the area of plate 1 and the regional tectonic setting of the area studied.

less than 1–2 km long, although several have continuous mapped lengths in excess of 25 km (Dibblee, 1954; Weber, 1963; Jennings, 1975).

The Elsinore fault zone is a prominent and youthful structural boundary that separates the Perris Block (English, 1926) along its eastern side from the Santa Ana Mountains along its western side. It is marked through most of its length by a bold topographic expression consisting of linearly aligned ridges, swales, and hollows. The term Elsinore trough, now commonly used to describe that part of the fault zone between Corona and upper Wolf Valley, aptly describes its structural character here.

Mesozoic metamorphic and plutonic rocks and Cenozoic sedimentary and volcanic rocks are complexly faulted along most of the length of the Elsinore fault zone. Faulted alluvial deposits of late Pleistocene and Holocene age occur here as well as to the south along the zone near the Coyote Mountains (Clark, 1975) and to the north along the zone near Corona (Weber, 1975). Together with microseismic data (Langenkamp and Combs, 1974), the faulted alluvial deposits suggest that the zone is currently active.

Seismically the Elsinore fault zone is relatively quiescent, especially when compared with other faults of the San Andreas system to the east (Allen, 1965). Microseismic activity measured during the summer and fall of 1972 increases southwar along the zone from 0.5 events/day near Lake Elsinore to 3 events/day near Monument Peak (Langenkamp and Comb 1974). Only one earthquake greater than M 4.5, a M 6 event i 1910 southwest of Elsinore, has been reported along the Elsinor fault zone in Riverside County during the past seven decad (Richter, 1958). However, approximately sixty earthquak (M2–M4) have occurred along the Elsinore fault zone betwe Lake Elsinore and the Agua Tibia Mountains within the for years between 1932 and 1972 (Hileman and others, 1973). these sixty events, ten were M 3.5 or slightly greater, and on five were M 4 or slightly greater.

First-motion studies by Langenkamp and Combs (1974) ind cate that fault motion along the Elsinore fault zone is comple Geologic studies by others (Dibblee, 1954; Mann, 1955; Eng 1959; Gray, 1961; Weber, 1963, 1975, 1976; Clark, 1975) repo strike-slip, normal, and thrust faulting along different parts the zone. Right-stepping, strike-slip displacements are associat with the southern part of the zone adjacent to the western si of the Coyote Mountains (Dibblee, 1954, p. 27); near the Imp rial-San Diego County boundary (Clark, 1975); in the vicini of Julian (Weber, 1963); and in the Corona, Chino, and La Elsinore area (Weber, 1975). In addition, a series of low-angl westward-dipping thrust faults form a portion of the bounda between the Perris Block and the Santa Ana Mountains between Corona and Wildomar along the western margin of the Elsinore trough (Weber, 1975, 1976); whereas nearly vertically inclined normal faults constitute this boundary from south of Wildomar to Temecula (Mann, 1955).

Geologic mapping in the area of this study indicates that the eastern side of the Elsinore trough (Wildomar fault zone) is composed principally of right–stepping, strike–slip faults that have a west–dipping normal component; whereas the western side (Willard fault zone) is composed of a series of east–dipping, steeply inclined, normal faults. Combined movement on these faults along this part of the zone has resulted in the development of the dramatically elevated Santa Ana Mountains, the Elsinore trough, and the pronounced scarp that forms the boundary between them.

The faulted rock–stratigraphic succession mapped is divided into two parts:

(1) A subjacent Middle and Late Mesozoic age basement complex composed of low–grade metamorphic rocks of the Bedford Canyon Formation and Santiago Peak Volcanics and plutonic rocks of the southern California batholith.

(2) A superjacent series of sedimentary and volcanic rocks of Late Tertiary and Quaternary age, which includes the Santa Rosa Basalt, the Temecula Arkose, an unnamed sandstone and conglomerate formation, the Pauba Formation, terrace deposits, and alluvial debris.

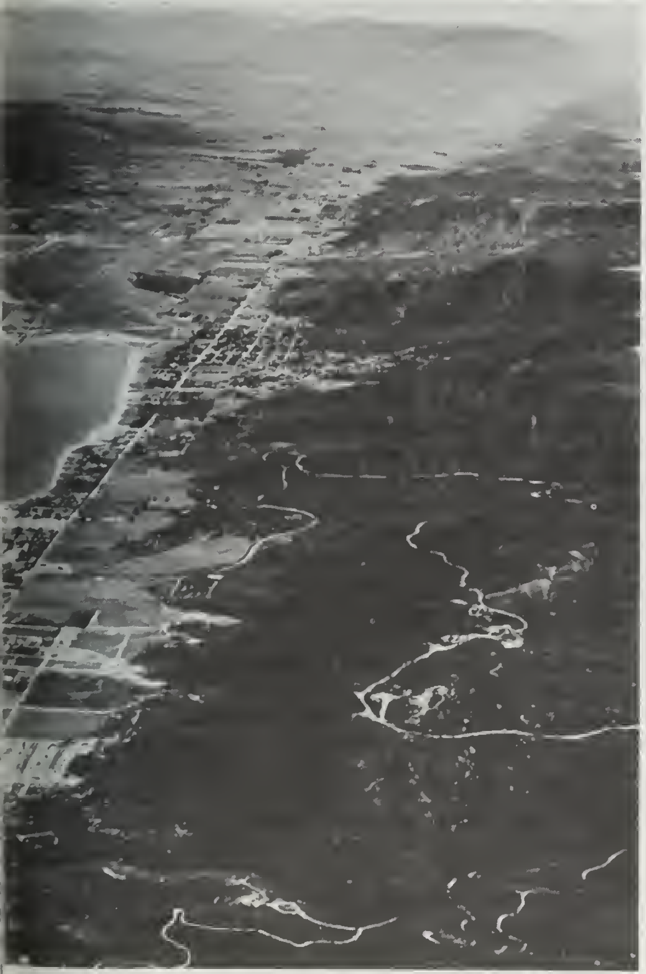


Photo 1. Willard fault zone between Lake Elsinore and the Agua Tibia Mountains.

Subjacent Rocks

Bedford Canyon Formation and Santiago Peak Volcanics

The Bedford Canyon Formation and the Santiago Peak Volcanics underlie a large part of the Santa Ana Mountains and are composed of a wide variety of silicified, low–grade metamorphic volcanic and sedimentary rocks (Larsen, 1948). The volcanic rocks range from metabasalt to metarhyolite but are predominantly metadacite and meta–andesite. The section is typified by breccia, agglomerate, volcanic conglomerate, and fine–grained tuff and tuff breccia. The metasedimentary rocks consist principally of metashale, metagraywacke, and porcelanite. These rocks form a complex and highly deformed succession that underlies much of the terrain in the area west of the Elsinore trough. They are hard where fresh, extremely resistant to erosion, and support the growth of dense chaparral.

Plutonic Rocks of the Southern California Batholith

The metamorphic rocks of the Bedford Canyon Formation and the Santiago Peak Volcanics are intruded by mid–Cretaceous age (Evernden and Kistler, 1970) plutonic rocks of the southern California batholith. In this area, plutons of granodiorite, quartz monzonite, quartz–bearing diorite, and gabbro are most abundant.

The granodiorite and quartz monzonite are included in the Woodson Mountain granodiorite of Larsen (1948). The granodiorite is coarse grained, light gray, and flecked with grains of black biotite and hornblende. Large grains of bluish–gray quartz and white plagioclase typify this rock. The quartz monzonite is also coarse grained and light gray. It contains light–colored plagioclase, pink microcline, and grayish quartz. Small grains of hornblende and biotite typify the rock and are present in proportions of about 5% each.

In the northernmost part of the area of this study, the Paloma Valley ring complex is exposed (Morton and Baird, 1976). The most abundant rocks of the complex consist of gabbro and granodiorite. Smaller proportions of schist, granitic pegmatite, and granophyre also occur locally in the complex. The mapping of the ring–complex (plate 1) is modified from Morton and Baird (1976) and from unpublished mapping of D.M. Morton (written communications).

Superjacent Rocks

Older Channel Deposits

A thin veneer of conglomeratic sandstone and pebble conglomerate crops out at an elevation of approximately 485 m at lat. 33°34'50"N., long. 117°90'34"W., beneath a basalt flow on the northern slope of Hogbacks, 3 km north of Murrieta Springs (plate 1). The surface upon which these older channel deposits rest has been correlated with the prominent and broadly exposed Perris surface to the north (Woodford and others, 1971). If this correlation is correct, the age, not only of these deposits but also of the Perris surface, predates that of the overlying middle Miocene ($11.6 \pm 1.1 \times 10^6$ years) basalt at Hogbacks (KA5, figure 2).

Santa Rosa Basalt

The Santa Rosa Basalt was named by Mann (1955) for the thin remnants of basalt, first described by Fairbanks (1892), that cap an erosionally dissected plateau along the west side of the Elsinore trough at Rancho Santa Rosa. The formation is composed mostly of a series of basaltic flows, but volcanic agglomerate and tuffaceous debris occur locally in exposures east of the trough at Vail Mountain. The flows in the type area are late Miocene in age, have an average thickness of 2 m and a combined thickness of approximately 30 m, and can be divided into a lower alkalic and an upper tholeiitic series (Hawkins, 1970).

Along the western side of the Elsinore trough, the basalt crops out 3 km southwest of Murrieta at Mesa de Burro and 2 km south of Wildomar on a very small isolated mesa (plate 1). The base of these, presumed once contiguous, flows is approximately 50 m lower in elevation at the Mesa de Burro site as a result of northeast tilting. Another small exposure of the basalt crops out in the central part of the Elsinore trough 600 m southwest of Chaney Hill between Murrieta and Wildomar (plate 1). Its location is the result of over 300 m of vertical movement along the Willard fault zone. Basalt has also been reported in the Elsinore trough approximately 747 m below the surface in an exploratory well located approximately 2 km southeast of Murrieta (Mann, 1955). The drillers' records for this well (Barnard no. 2 of Mann, 1955; Vernard no. 1 of the California Division of Oil and Gas) show "hard gray, broken rock and shale" for this interval, which is interpreted here as belonging to a well–lithified, fine–grained facies of either the Temecula Arkose or the unnamed sandstone and conglomerate formation in that soft gray shale was encountered below this horizon near the bottom of the well at a depth of more than 945 m.

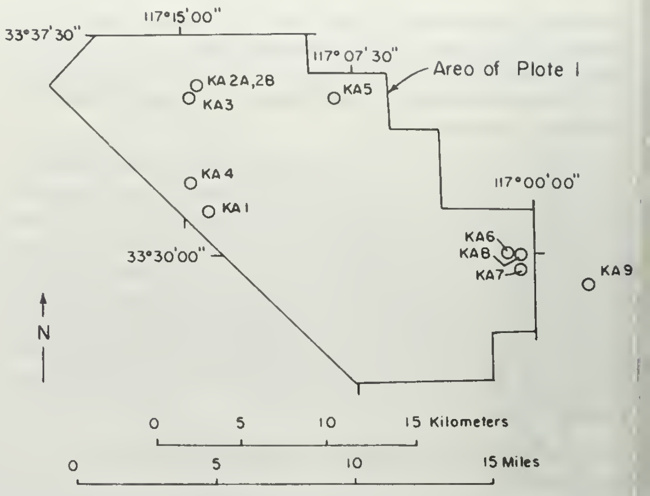
Along the eastern side of the Elsinore trough, the Santa Rosa Basalt crops out 5 km northeast of Murrieta at Hogbacks. The base of the flow at Hogbacks is approximately 105 m lower than it is on the western side of the trough at Mesa de Burro. Southwest of Hogbacks, a fault block in which the basalt is exposed suggests that there has been approximately 90 m of vertical separation there with the west side downdropped. Also to the east of the Elsinore trough, basalt is exposed 3 km west of Vail Lake in the upper reaches of Temecula Creek. Along the south side of the creek in the slopes underlying Vail Mountain, the basalt is offset vertically more than 100 m by small northeast–striking faults. The elevations of the bases of essentially undisturbed flows that cap Vail Mountain are exactly the same as those at Mesa de Burro.

The regional distribution of the basalt remnants (Larsen, 1948) suggests that these flows might once have been contiguous over an area of more than 500 km^2. If the flows were limited to an area of about this size, definite post late Miocene constraints exist for their lateral separation along the Elsinore fault.

A late Tertiary age was first assigned to these rocks by Larsen (1948) based mainly on their topographic position. Potassium–argon analyses of basalt from the southern end of Mesa de Burro suggest an age of 8.3 ± 0.5 m.y. (Hawkins, 1970). Subsequent analyses of basalt from Mesa de Burro, the Elsinore trough, Hogbacks, and Vail Mountain yield an average age of 9.6 ± 0.7 m.y. (figure 2).

Temecula Arkose

The Temecula Arkose was named for the excellent exposures of Pleistocene nonmarine fluviatile deposits that underlie the area southeast of Temecula at the Pechanga Indian Reservation (Mann, 1955). The formation in its type area consists mostly of pale greenish–yellow, well–indurated, medium– and coarse–grained sandstone beds that average a meter thick. Thin discontinuous beds of fine–grained, tuffaceous sandstone, siltstone, and claystone are common and locally interstratified with the massive sandstone beds. Pebble and cobble conglomerate interbeds composed of locally derived basement rock clasts are also common and range in thickness from a few centimeters to a meter or more. The formation is typified by thick massive beds of cross–stratified sandstone, imbricated clasts, a lateral variation in grain size within individual beds, channel and fill features,



Sample	Rock Type	Latitude	Longitude	Age
KA 1	Basalt	33°30'53"N.	117°13'42"W.	11.0±0.5 X 10^6 years
KA 2A	Tuff	33°34'48"N.	117°14'13"W.	9.9±2.5 X 10^6 years
KA 2B	Tuff	33°34'48"N.	117°14'13"W.	18.7±0.8 X 10^6 years
KA 3*	Basalt	33°34'35"N.	117°14'35"W.	Undetermined
KA 4*	Basalt	33°32'02"N.	117°14'47"W.	9.5±6.5 X 10^6 years
KA 5	Basalt	33°34'43"N.	117°09'48"W.	11.6±1.1 X 10^6 years
KA 6*	Basalt	33°29'57"N.	117°00'50"W.	7.9±3.8 X 10^6 years
KA 7	Basalt	33°29'45"N.	117°00'30"W.	7.7±0.5 X 10^6 years
KA 8	Basalt	33°29'54"N.	117°00'54"W.	8.25±0.7 X 10^6 years
KA 9*	Tuff	33°28'32"N.	116°57'38"W.	Undetermined

* Extremely high percent of atmospheric argon.

Figure 2. Index map showing locations of rocks dated isotopicall by K/Ar analyses and a list of each experimental age. ***Analyse by D. Krummenacher, San Diego State University; sample 2 analyzed by Geochron Laboratories, Cambridge, Massachusetts.***

lack of cementation, and poor sorting. Approximately 10 k east of the type area, however, at Vail Lake and Radec (figur 3), a facies of the Temecula Arkose is recognized that generall lacks conglomeratic interbeds and is finer grained, less massive and only locally cross stratified. Interbedded tuffaceous sandstone beds, in all respects similar to those at Pechanga, crop ou at Vail Lake and Radec. Fossil mammals collected from Pechanga, Vail Lake, and Radec lie stratigraphically within 25 m of on another and suggest a late Pliocene (Blancan) age for that par of the section (Golz and others, in press). The fauna reporte includes *Nannippus, Hypolagus, Tetrameryx, Equus,* an *Odocoileus* and collectively restricts the age of these beds t 2.2–2.8 × 10^6 years (Lindsay and others, 1975).

The Temecula Arkose has a maximum preserved thickness c 500 m at Pechanga, 125 m at Vail Lake, and 85 m at Rade (figure 3). The beds at Vail Lake and at Radec have many c the characteristics to suggest they were deposited in a relativel quiet, sparsely diatom–bearing, lacustrine environment; wherea those of the Pechanga area probably were deposited in a moderately high–energy, fluviatile, or distal alluvial fan environmen

Unnamed Sandstone and Conglomerate Formation

An unnamed sandstone and conglomerate formation simil lithologically to the Temecula Arkose crops out discontinuousl from the upper reaches of Santa Gertrudis Creek west to Wildomar (plate 1). These rocks are unconformably overlain by t Pauba Formation and in turn may unconformably overlie t

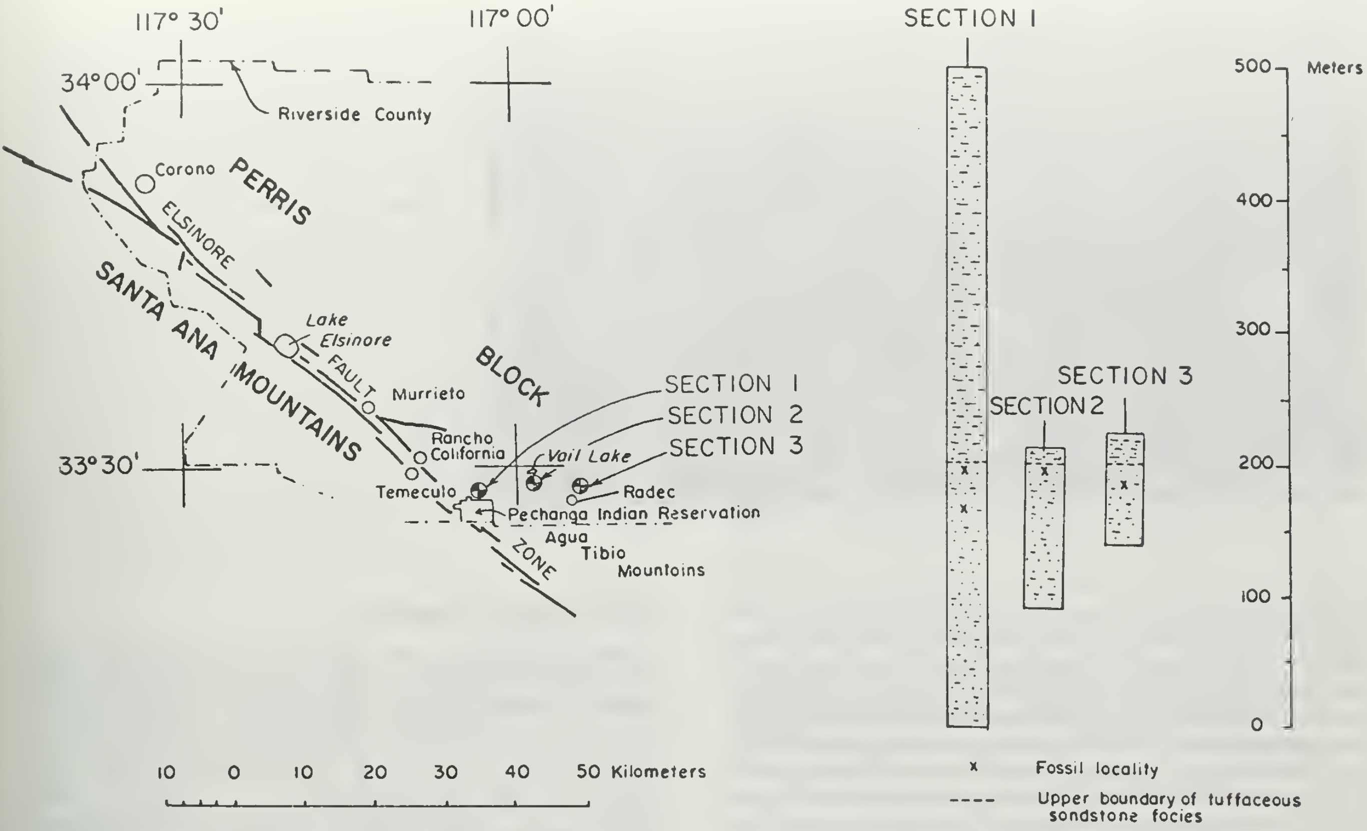


Figure 3. Index map and columnar sections showing fossil localities (modified from Golz and others, 1977).

Temecula Arkose in the subsurface (figure 4). The maximum exposed thickness of the formation is estimated to be 75 m; though because of faulting, low relief, and the discontinuous outcrop pattern, this figure is questionable.

The formation is composed mostly of pale greenish–yellow, medium–grained, friable, caliche–rich sandstone, which, in its northwesternmost part along the Wildomar fault zone, grades laterally and abruptly to a cobble–and–boulder conglomerate facies composed entirely of locally derived plutonic, metamorphic, and volcanic clasts set in a coarse–grained brown sandstone matrix. The composition and character of the conglomerate—especially the abundance of quartz–bearing gabbro similar to that immediately east of the outcropping conglomerate near Wildomar, steeply inclined, west–dipping, crossbedded sandstone interbeds, and the presence of volcanic clasts petrographically similar to those at Hogbacks—suggest an eastern and northeastern source area for these rocks.

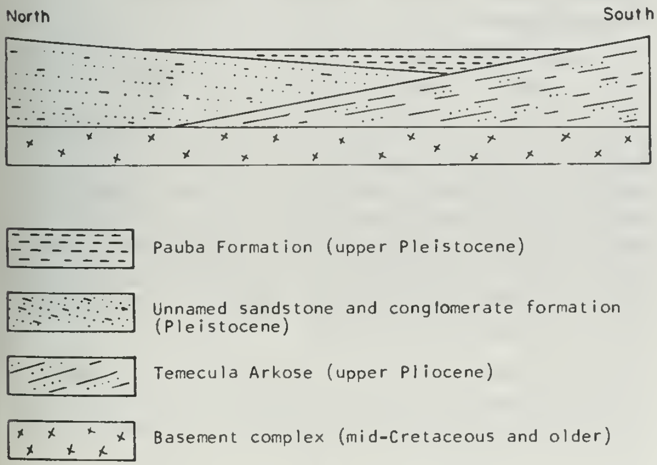

North
South
Pauba Formation (upper Pleistocene)
Unnamed sandstone and conglomerate formation (Pleistocene)
Temecula Arkose (upper Pliocene)
Basement complex (mid-Cretaceous and older)

Figure 4. Diagrammatic relationship between the Pauba Formation, an unnamed sandstone and conglomerate formation, the Temecula Arkose, and the rocks of the Mesozoic basement complex.

A 2–to–3–m–thick ash horizon interstratified with sandstone near Chaney Hill, referred to as the Wildomar kaolin deposit (Dietrich, 1928) and considered a part of the Temecula Arkose (Mann, 1955), is correlated with the 0.7–m.y.–old Bishop Ash (Merriam and Bischoff, 1975). A. Sarna–Wojcicki of the U.S. Geological Survey and Glenn A. Borchardt of the California Division of Mines and Geology have also correlated the Wildomar kaolin deposit with the Bishop Ash by neutron–activation analysis (written communication). Detrital biotite originally considered to be part of the primary ash fall mixed with initial biotite gave two erroneous K/Ar ages of 9.9 ± 2.5 and 18.7 ± 0.8×10^6 years (figure 2).

Pauba Formation

The Pauba Formation, a succession of late Pleistocene siltstone, sandstone, and conglomerate, was named by Mann (1955) for exposures at Rancho Pauba, approximately 5 km southeast of Temecula in Rancho California. Rocks in the type area crop out nearly continuously for more than 5 km in the north–facing bank of Temecula Creek in lower Pauba Valley.

The Pauba Formation has an exposed thickness of approximately 75 m and is composed of (1) a light–brown, moderately well–indurated, extensively crossbedded, channeled and filled sandstone and siltstone facies that contains occasional intervening cobble–and–boulder conglomerate beds and (2) a grayish–brown, well–indurated, poorly sorted fanglomerate and mudstone facies.

The sandstone and siltstone facies is widespread and crops out in its main part along the eastern side and central portion of the Elsinore trough from near Wildomar south through Pauba Valley and east to its unconformable contact with older sedimentary, plutonic, and metamorphic rocks in the vicinity of Skunk

Photo 2. Wildomar fault zone near Rancho California.

Hollow, Buck Mesa, and upper Temecula Creek (plate 1). The slopes underlying these rocks are subdued and commonly mantled by a 0.5–to–1–m–thick soil horizon. Discontinuous conglomerate interbeds 10–50 cm thick occur locally in the easternmost exposures of the siltstone and sandstone facies but are essentially absent in the westernmost exposures near Wildomar. West–dipping crossbeds, channel–and–fill features, and a variation in grain size along strike within individual beds are also common to the easternmost exposure. These factors, when considered together, suggest that this part of the Pauba Formation was deposited in a fluviatile environment by a river system whose headwaters, though certainly at a considerably higher base level, may have been coincident with the present–day drainage of Temecula Creek.

The fanglomerate facies of the Pauba Formation crops out nearly continuously along the eastern and central parts of the Elsinore trough from Temecula north to Cole Canyon. The clasts of the fanglomerate have been derived principally from the plutonic and metamorphic basement complex. Clasts of the fanglomerate are angular and set in a well–lithified mudstone matrix which has also been derived from the local basement terrain. The mudstone swells considerably by the addition of water and, based on field observation, has an extremely high plasticity index. The fanglomerate facies was probably deposited by sheetwash activity on initially moderately steep slopes as small mud flows that coalesced to form the continuous debris apron that now mantles these slopes. The fanglomerate facies is now partly dissected by east–flowing drainages that carry detritus to Murrieta Creek in the central part of the trough. Where these drainages have cut deeply into the bedrock, an interfingered relationship between the fanglomerate and the finer grained sandstone and siltstone facies has been exposed. Because the facies change occurs over a distance of several hundred meters, the contact between these units is an approximation of where surface exposures belong entirely to the finer grained facies along the eastern side of the contact.

The late Pleistocene age assigned to the Pauba Formation is based on its superpositional relationship with the unconformably underlying approximately 0.7–m.y.–old unnamed sandstone and conglomerate formation (plate 1) and on a small fossil assemblage reported by Mann (1955). The fossils, which include *Equus,* occur approximately 1 km northeast of Interstate Highway 15 (previously U.S. Highway 395) in the northwest bank of Santa Gertrudis Creek. Mann (1955, p. 14) states, "The horse teeth are modern in every respect and are much less indurated than the horse teeth found in the Temecula Arkose."

Dripping Springs Formation

The Dripping Springs Formation was named by Mann (1955) for exposures of fanglomerate that crop out immediately east of the area in road cuts along State Highway 71 in the Vail Lake 7.5′ U.S. Geological Survey quadrangle. Only two small exposures of these beds occur in the area studied, and they lie in the vicinity of the Yampa Ranch (lat. 33°27′50″N., long. 117°00′12″W.) and the eastern Pechanga Indian Reservation (lat. 33°26′10″N., long. 117°02′40″W.).

These deposits are composed of pebble, cobble, and boulder fanglomerate in a reddish–brown, poorly consolidated, poorly sorted sandstone matrix. The clasts are mostly subangular to subround and have been derived from the local basement rocks composed of gabbro, granodiorite, and hybrid gneiss.

The age of the Dripping Springs Formation is not known, though it is certain from field relationships that it post–dates the age of the Temecula Arkose and is either equivalent to, or slightly younger than, the late Pleistocene Pauba Formation.

Landslide Deposits

Very few landslides occur in the area studied. The largest of these were mapped and are shown on plate 1. The location and a brief description of each landslide is given in table 1.

Terrace Deposits

Quaternary terrace deposits crop out as isolated remnants of a once–widespread sedimentary cover. These deposits are composed mostly of reddish–brown, well–consolidated, coarse–grained sandstone and conglomeratic sandstone that contain stringers of pebble and cobble conglomerate. They are best preserved east of the Wildomar fault zone and south of the Murrieta Hot Springs fault between Buck Mesa and Pauba Valley. Here the surface upon which the terrace deposits rest lies between approximately 455 m on the east and 375 m on the west and, though regionally elevated and very slightly tilted to the west, is tectonically unmodified (figure 5).

South of Pauba Valley, in the area east of the Wildomar fault zone, the terrace is steeply tilted to the northwest (figure 5) as a result of youthful uplifting of the Palomar Mountain tectonic block.

Only one small terrace has been mapped on the southwest side of the Elsinore fault zone, and its age relationship to those to the west of the fault zone is uncertain. This terrace, which lies near

Table 1. Landslide deposits shown on plate 1.

Landslide number and location		Geologic unit	Description
1.	33°37'15"N., 117°19'20"W.	Quartz monzonite and granodiorite	Individual landslides have not been shown. The large steeply inclined alluvial fan complex appears to be underlain in part by large landslide blocks that may have originated from the steep cliffs to the west of the fan itself.
2a. 2b.	33°33'57"N., 117°15'45"W. 33°33'50"N., 117°15'15"W.	Granodiorite	Two small landslides have been caused by the steep topography and basal undercutting by rapid stream cutting in Slaughterhouse and Cole Canyons.
3.	33°28'12"N., 117°18'42"W.	Metamorphic rocks of the Bedford Canyon Formation and plutonic rocks of the southern California batholith.	Several landslides have been caused by the rapid uplift and stream erosion along the Santa Margarita River drainage. The landslides occur along or near the steeply inclined intrusive contact between the plutonic and metamorphic rocks.
4a. 4b.	33°33'45"N., 117°10'35"W. 33°32'38"N., 117°10'52"W.	Pauba Formation	Two small landslides are shown here based on subtle topographic expression seen on low-sun-angle stereo photographs. Because plowing has nearly obliterated the surface expression of the landslides, they cannot be readily confirmed by site inspection.
5a. 5b. 5c. 5d.	33°29'35"N., 117°00'55"W. 33°29'55"N., 117°00'42"W. 33°29'50"N., 117°00'40"W. 33°29'43"N., 117°00'37"W.	Hybrid rocks associated with intrusive rocks of the southern California batholith.	These four landslides are rotational slumps caused by the incompetence of the highly fractured bedrock in which they lie, extremely steep topography, and basal undercutting by small tributaries of Temecula Creek.

the mouth of Cole Canyon, is capped by a thin veneer of poorly consolidated pebble conglomerate in a light-brown, coarse-grained sandstone matrix. It lies at approximately 370 m elevation and is tilted a degree or two northwest. Quaternary uplift of the Santa Ana Mountains and consequent erosion have obliterated most of this surface and perhaps other terraces that once existed along the west side of the fault zone.

Stream Terrace Deposits

Very youthful (probably late Pleistocene), poorly consolidated stream terrace deposits composed of locally derived conglomerate and sandstone have been preserved (1) along the north bank of Temecula Creek near the point where sediment issues from the narrow canyon below Vail Lake onto the uppermost broadly alluviated part of Pauba Valley and (2) along the north banks of the middle and upper reaches of Pechanga Creek on the Pechanga Indian Reservation. As a result of regional uplift, these deposits are extensively dissected. These few beds represent the remnants of what was once probably a more widely spread unit that flanked not only the Temecula and Pechanga drainages but also other major drainages of the area.

Older Alluvium

Alluvium, older than that which underlies many of the modern drainages, crops out fairly continuously along the eastern boundary of the area between Buck Mesa and Winchester Road. These deposits cap a low-relief, undulating surface that occurs between approximately 400 m and 425 m elevation. A dark reddish brown characterizes the less-than-10-m-thick, poorly consolidated, fine-grained sand, silt, and clay succession.

These older alluvial deposits were locally derived from the surrounding plutonic and sedimentary bedrock some time after the deposition of the late Pleistocene Pauba Formation, upon which they locally rest. The terrace deposits mapped in the area southwest of Buck Mesa, in Rancho California, both to the north and south of Pauba Valley, are closely associated lithologically and genetically with these beds and were deposited during the same relatively higher base level period in late Pleistocene time.

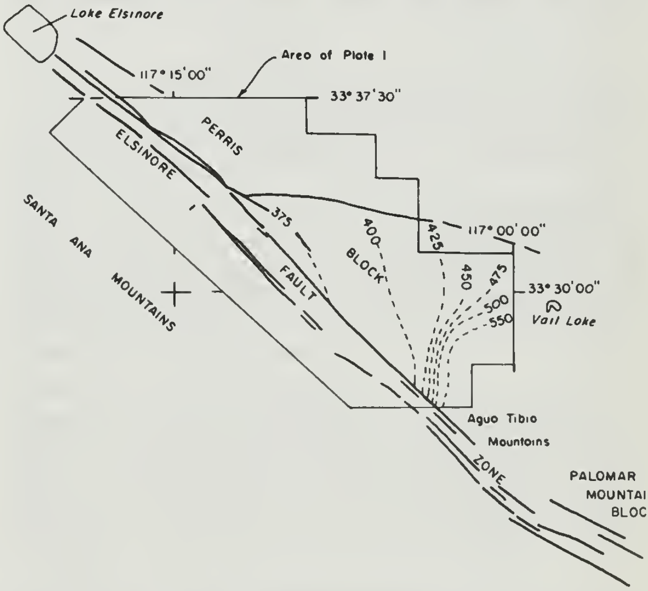


Figure 5. Index map showing base of tectonically deformed late Pleistocene terrace deposits.

The now highly dissected surface upon which both of these units rest has been contoured (figure 5) to illustrate its gentle westerly dip in the vicinity of Rancho California and its tectonically elevated position in the southern part of the area.

Alluvium, Colluvium, and Slope Wash

Alluvium, colluvium, and slope-wash deposits of late Pleistocene and Holocene age are shown, for the purpose of this study, as a single stratigraphic unit. The alluvial deposits of the modern drainages grade imperceptibly with colluvium and slope-wash deposits that flank the lower slopes adjacent to Murrieta, Pauba, and Wolf Valleys. These deposits are lithologically variable and generally reflect the local source material from which they were derived.

The alluvium is mostly moderately well-sorted, poorly consolidated sand and silt with interspersed tongues of pebble and cobble conglomerate. The colluvium and slope-wash deposits are composed principally of poorly consolidated fine-grained sand, silt, and clay derived from the soil of the local bedrock.

Water and exploratory well data (Giessner and others, 1971) suggest that the alluvium underlying Murrieta Valley in the Elsinore trough is more than 75 m thick near Wildomar and more than 150 m thick near Murrieta. These thicknesses are based on the deepest water wells drilled in the respective areas and on drillers' logs that report the depth to which poorly consolidated sand and gravel deposits occur. One exploratory oil well (Berghofer 1) drilled by Positive Oil Company during the summer of 1957, in the valley floor between the Wildomar and Willard fault zones, approximately 1 km north of Temecula (lat. 33°30'17"N., long. 117°90'12"W.), penetrated more than 1200 m of sedimentary strata (table 2). The first consolidated material, "hard sand", was encountered 464 m below the surface of the valley floor. How much of this 464-m section is alluvium and at exactly what depth the contact between the Pauba Formation and alluvium exists are not known. Because the Pauba Formation is composed, in part, of older alluvial and fluviatile debris and is at best only moderately well consolidated, it is difficult to separate from the younger alluvial deposits by use of the available boring logs.

Table 2. Selected exploratory and water wells with the location and minimum depth drilled in sedimentary rocks as inferred from drillers' logs.

Well name	Location	Depth
Prospect no. 1	Sec. 18, T.6S., R.2W.	594 m
Stuart no. 1	Sec. 18, T.6S., R.4W.	794 m
Berghofer no. 1	Sec. 2, T.8S., R.3W.	1,234 m
Unnamed water well (State of California no. 7S 3W 6K1)	Sec. 6, T.7S., R.3W.	413 m
Murrieta Valley Oil Company no. 1	Sec. 15, T.7S., R.3W.	341 m
Vernard no. 1	Sec. 21, T.7S., R.3W.	946 m
Watt no. 1	Sec. 23, T.7S., R.3W.	291 m
Watt no. 2	Sec. 23, T.7S., R.3W.	849 m
Unnamed water well (State of California no. 8S 2W 17M1)	Sec. 17, T.8S., R.2W.	753 m

FAULTING

An age has been assigned to each fault shown on plate 1 based on the age of the geologic unit that it offsets. The symbols H, L, Q, P, and T have been used to indicate that a fault has displaced Holocene, late Pleistocene, Quaternary, Pliocene, and Tertiary or older rock units respectively. Faults known to be overlapped by Holocene or late Pleistocene age strata have been assigned an h or an l, respectively, in addition to the upper case age designation. A fault labeled P/h, for example, displaces the Temecula Arkose but does not offset overlying Holocene sediment. The age of each faulted rock unit is discussed in the preceding section and is summarized in table 3.

The faults mapped are those inferred from geomorphic evidence (dashed) and those known to exist from geologic evidence (solid). The geomorphic features noted and considered to have a tectonic or post-tectonic erosional origin were observed on low-sun-angle stereoscopic aerial photographs. These features are linearly aligned, fault-produced topographic features, ponded alluvium, closed depressions, deflected drainages, and faceted spurs. In addition and where occurring with geomorphic evidence of faulting, linearly aligned vegetation and abrupt linear color contrasts considered to be manifestations of a difference in the elevation of the ground-water table or a difference in rock and soil type have been used locally as supporting evidence of faulting. Each dashed fault is labeled by an abbreviation that indicates which geomorphic features were used as criteria to suggest faulting. The faults shown by solid lines are based on observations made generally first on aerial photographs but later documented in the field.

The Elsinore fault zone consists of four parts: (1) Willard fault zone, the boundary faults between the Elsinore trough and the Santa Ana Mountains; (2) Wildomar fault zone, the boundary faults between the Elsinore trough and the Perris Block; (3) Wolf Valley fault zone, a series of northwest-striking faults within the south-central part of the trough that perhaps represent an eastern splay of the Willard fault zone; and (4) Murrieta Hot Springs fault zone, a group of faults that strike nearly normal to the prominent northwest trend of the Elsinore trough.

The Willard fault zone (Engel, 1959) was named for the high-angle faults that form the boundary between the Elsinore Mountains on the west and the Elsinore trough on the east. These faults, at the surface, separate the igneous and metamorphic rocks of the Mesozoic basement complex from poorly consolidated sediments of Quaternary age.

Within this area, the Willard fault zone is composed of a series of northwest-striking, east-dipping, high-angle normal faults. Most individual faults of the zone can be traced for only a kilometer or two and many for less than a few hundred meters. The faults have a complex discontinuous relationship to one another and only as a group form a through-going zone.

In the northernmost part of the area, southwest of Lake Elsinore and directly west of Wildomar, the Willard fault zone is clearly marked by a bold linear topographic expression. This prominent topography persists southwest from Wildomar for approximately 2 km to the mouth of Slaughterhouse Canyon. From this area south to Murrieta, approximately 6 km, the fault zone is mostly obscured by the Holocene alluvium of Slaughterhouse, Cole, and Miller Canyons. Fault-related topography in this area has been obliterated from all but a few locations (plate 1). Along this same segment, a series of north- and northeast-striking faults obliquely intersects and questionably offsets the Willard fault zone (plate 1).

South from Miller Canyon to upper Wolf Valley, linear topography again clearly marks the trace of the fault zone. Small drainage channels are clearly deflected right laterally along this segment of the zone. Faulted Quaternary age sediments and a youthful topographic expression suggest a moderately young age for this part of the zone.

Large-scale vertical and small-scale horizontal offsets have been proposed for the Willard fault zone in a model suggesting rather uniform block faulting, down to the east, that formed the western portion of the Elsinore trough (Jahns, 1954; Mann, 1955). The eastern side of the trough, in this model, is formed along a similar set of dip-slip faults (Wildomar fault zone) that have relative downward motion to the west. Together these faults form a multistepped graben that is now filled with a thick succession of presumably Late Tertiary and Quaternary age sediment.

Three exploratory wells have been drilled in Murrieta Valley between the Willard and the Wildomar fault zones: Prospect no.

Table 3. Faulted rock units.

Rock unit	Age	Determined by	Symbol assigned to faults	
			Faulted	Not faulted
Qal—Alluvium, colluvium, and slope wash	Holocene	Superposition, induration, lithology.	H	h
Qps, Qpf—Pauba Formation	Late Pleistocene	Superposition, lithology, fossil mammals.	L	l
Qus, Quc—Unnamed sandstone and conglomerate formation	Pleistocene (0.7 m.y.)	Superposition, lithology, neutron activation analysis.	Q	—
Tta—Temecula Arkose	Late Pliocene (2.2-2.7 m.y.)	Superposition, fossil mammals, geomagnetic chronology.	P	—
Tsr—Santa Rosa Basalt	Late Miocene (9 m.y.)	K/Ar.	T	—
Kqm, Kgd, Kgb, Jm—Rocks of the plutonic and metamorphic basement complex	Mid-Cretaceous and older	K/Ar, fossil mollusks.	T	—

1 located 2 km south of Lake Elsinore, Stuart no. 1 located 1 km northeast of Wildomar, and Berghofer no. 1 located 1 km north of Temecula. These wells penetrated 549 m, 794 m, and 1234 m of sedimentary rock, respectively (table 2). These well depths indicate that a relatively thick, mostly sandstone succession of strata abuts the Mesozoic basement rock along the Willard fault zone. Because none of these borings encountered the Mesozoic basement rock, the thickness of the sedimentary sequence in the central part of the fault zone is unknown. Exploratory wells drilled along the eastern side of the Wildomar fault zone—1 km southeast of Oak Springs Ranch (unnamed water well, State of California no. 7S 3W 6K1), at Temecula Hot Springs (Murrieta Valley Oil Company no. 1), 1 km southwest of Temecula Hot Springs (Vernard no. 1), 2 km southeast of Temecula Hot Springs (Watt no. 1 and 2) and 1 km west of Rancho Pauba (unnamed water well, State of California no. 8S 2W 17M1)—penetrated 413 m, 341 m, 946 m, 291 m, 849 m, and 753 m of sedimentary rock, respectively, and again did not encounter the Mesozoic basement complex. These well data and water well records reported by Giessner and others (1971) indicate that a relatively thick succession of strata exists to the east of the Wildomar fault zone. The data also suggest that the contact between sedimentary rocks and the Mesozoic basement complex may rise from a subsurface depth of more than 1200 m in the central part of the trough as a relatively steep and irregular surface to the east, where it crops out along the eastern side of the area (figure 6).

Between Lake Elsinore and Chaney Hill (lat. 33°34′47″N., long. 117°14′23″W.), small sag ponds, faceted spurs, and laterally deflected stream channels clearly mark the most recent breaks of the Wildomar fault zone. Along this segment of the zone, an unnamed Pleistocene sandstone–and–conglomerate formation is offset more than 5 km right laterally. This offset is based on the horizontal separation of a facies boundary between sandstone and conglomerate that is well exposed east of Wildomar, along the northeastern side of the fault, and southeast of Chaney Hill, along the southwestern side of the fault (plate 1). The conglomerate facies here is composed of clasts derived from the very distinctive Santa Rosa Basalt, gabbro and granodiorite set in an iron–stained, poorly sorted sandstone matrix. The sandstone facies is pale greenish yellow, medium grained, friable, and rich in caliche. The facies change itself is unique in that it is extremely abrupt. Engel (1959) points out that the upthrown side of the Wildomar fault zone is to the northeast near Wildomar and to the southwest at Lake Elsinore. This apparent reverse relationship is the result of differential weathering of the two facies along the strike of the fault.

South from Chaney Hill to the town of Murrieta, the Wildomar fault zone is less sharply defined by strong physiographic expression. This segment of the zone is underlain by, and displaces, older alluvial deposits of the late Pleistocene age Pauba Formation.

Between Murrieta and Interstate Highway 15, little evidence exists for the location of the fault. A ground–water barrier coincident with the zone through this area (Moreland, 1972) exists in Quaternary alluvial deposits of Murrieta Creek. The water table is displaced downward along this part of the zone on an average of 10 m to the west.

South from Interstate Highway 15 to upper Wolf Valley in Rancho California, a strongly linear erosional scarp marks a recent trace of the Wildomar fault zone. The width of the fault zone is uncertain through this area because the lowlands west of the prominent eastern scarp, in Pauba and Wolf Valleys, are underlain by apparently unfaulted modern alluvium that has been cultivated in recent years.

Springs flowing along the low–lying hills immediately east of the fault zone, south of Pauba Valley, fill several small earth–filled dam and reservoir sites that are built astride this segment of the fault zone. These fills have undergone no apparent tectonic deformation since their construction more than forty years ago.

West of the Wildomar fault zone, in the central part of Wolf Valley, Holocene alluvium is offset by a series of mostly northwest–striking *en échelon* faults that constitute the Wolf Valley fault zone.

The Wolf Valley fault zone is marked by a subtle topographic expression on the valley floor consisting of aligned hills and swales in cultivated farm lands. Locally, youthful faulting is suggested by steeply tilted and dissected Holocene alluvium exposed in the banks of Pechanga Creek. Along one segment, on the Pechanga Indian Reservation, closed depressions lie adjacent to a linear scarp that marks the fault for approximately 2 km.

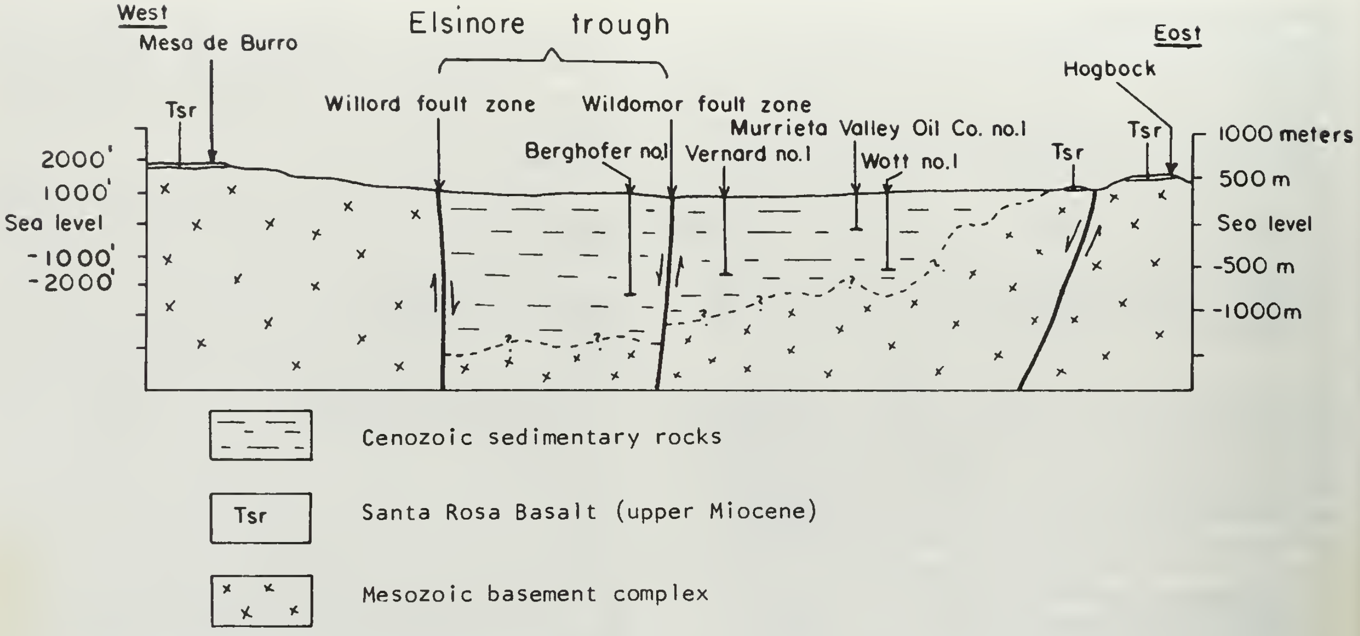


Figure 6. Diagrammatic structure section across Murrieta Valley.

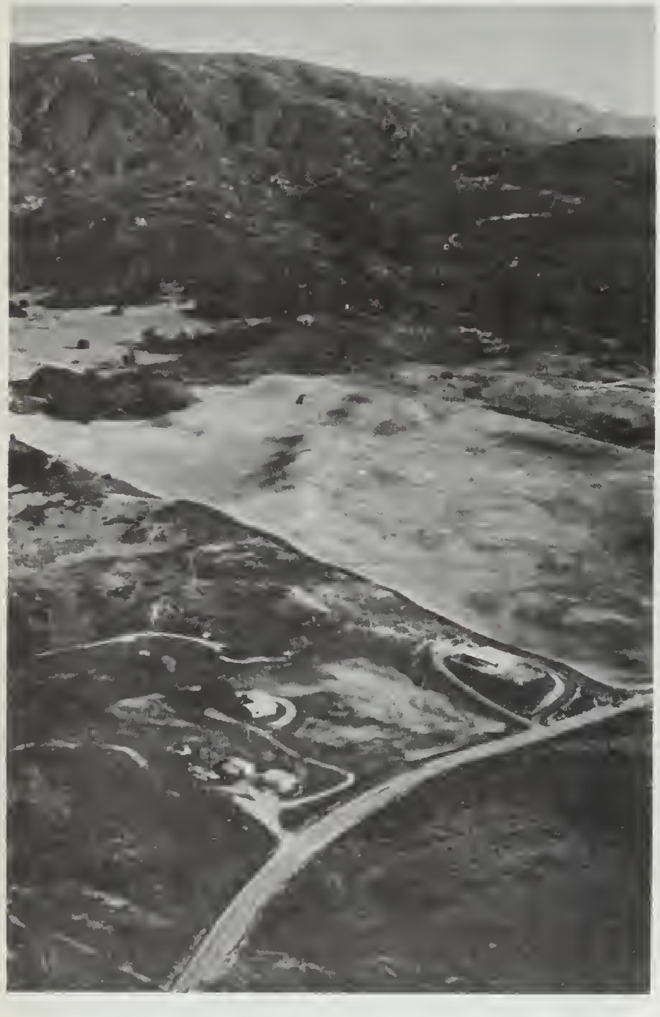


Photo 3. Wolf Valley fault zone.

The Wolf Valley fault zone appears to branch east from the Willard fault zone, 2–3 km southeast of Temecula, though this questionable relationship is masked by the modern alluvium that has issued from several northeast–flowing tributaries that feed Pechanga Creek along the southern side of Wolf Valley.

Supplementary to the prominent northwest–trending faults that define the Elsinore trough are several east–striking faults that constitute a discontinuous zone of faulting between Murrieta and Buck Mesa (plate 1). The most prominent of these faults is the Murrieta Hot Springs fault zone. The Murrieta Hot Springs fault zone intersects and is either cut off by, or is an eastern branch of, the Wildomar fault zone at Murrieta. It is composed of several faults that have an average strike of N.75°W. and a dip of 80°S. The Murrieta Hot Springs fault can be mapped continuously from Murrieta to Murrieta Hot Springs, approximately 5 km. Immediately east of Murrieta, the fault trace is partly masked by cultivation. However, in the vicinity of Warm Springs Creek (plate 1), the fault is well exposed and forms a ground–water barrier along which artesian warm water rises. The fault extends southeast from Murrieta Hot Springs to Buck Mesa, approximately 10 km, based on well data (Giessner and others, 1971) that defines a ground–water barrier similar to, and along strike with, the one at Warm Springs Creek. Rocks of the Mesozoic basement complex crop out discontinuously along the northern side of the fault between Warm Springs Creek and Tucalota Creek, a distance of approximately 3 km (plate 1). Quaternary and questionable upper Tertiary sandstone crops out and extends to a subsurface depth of more than 849 m along the southern side of the fault near Murrieta Hot Springs (plate 1).

LIQUEFACTION POTENTIAL

Liquefaction is defined as the transformation of a sediment from a solid to a liquid state by increasing pore–water pressure (Youd, 1973). A pore–water–pressure increase may occur in water–bearing sediment during strong shaking in an earthquake. Ground failure with associated widespread structural damage resulting from seismically induced shaking and liquefaction of sediment has occurred in association with enumerable major earthquakes throughout the world. Liquefaction should be considered a primary seismic hazard in land–use planning in the deeply alluviated, periodically water–saturated portions of the area.

The potential for liquefaction is an estimate taken from the analysis of maximum horizontal ground acceleration, duration of shaking, depth of water table, and depth and resistance of penetration (Youd and others, 1975). The potential for liquefaction is highest in clay–free granular sediments (sand and silt fraction) that are water saturated, poorly consolidated, and well sorted (Lajoie and Helley, 1975). This is not to imply that such materials will liquefy if shaken but simply that they are more susceptible to liquefaction as a result of shaking than are undersaturated, poorly sorted consolidated sediments.

The broadly alluviated floors of Murrieta, Pauba, and Wolf Valleys are underlain in part by poorly consolidated, periodically water–saturated, moderately well–sorted sand and silt deposits. Because these deposits are transected by geologically youthful faults, it is important to note that liquefaction of these sediments with resulting ground failure could occur given a strong earthquake with a moderately long duration and a relatively high horizontal ground acceleration.

The sand–and–silt valley fill varies considerably in lithology and includes partly interfingering alluvium, slope wash, and colluvium. Each of these units, because of the compositional variables, will behave differently during shaking. A soil survey of the valley fill (Knecht, 1971) shows that more than twenty soil types are developed on the valley–fill sediment, indicating that the upper few meters of this succession is characterized by extremely varied lithologies.

Depth–to–water measurements were collected for most of the valley area during the eight months beginning September 1967 and ending April 1968 (Giessner and others, 1971). The depth–to–water can change rapidly as a result of domestic pumping and natural recharge, and therefore the contouring of this data is presented only to indicate those areas where near–surface ground water is known to occur periodically. During periods of extremely high annual rainfall, much of the valley area could be underlain by a relatively high water table; and conversely for an exceptionally dry period.

In conclusion, even though the valley fill is heterogeneous and only periodically water saturated, it does contain some sediment that, when saturated, has a relatively high potential for liquefaction.

The liquefaction potential for any site underlain by the valley fill sequence can be assessed prior to construction. Seed and Idriss (1971) present a "simplified procedure for evaluating soil liquefaction potential" designed for use in soils underlain by relatively flat slopes and with densities less than 80 percent.

A prerequisite to the meaningful use of this procedure, however, is to establish the number of significant strong–motion cycles and resulting maximum horizontal surface ground accelerations that might be expected in the event of a major earthquake. These numbers are especially difficult to determine for an area where no great historic earthquakes have occurred.

SUMMARY

(1) The Elsinore fault zone between the town of Wildomar and upper Wolf Valley in southern Riverside County is composed of a large number of mostly northwest–striking faults that form a 1–to–2–km–wide asymmetrical trough filled with more than 1 km of Cenozoic sedimentary rocks.

(2) These faults form a prominent boundary, which is marked by a bold topographic expression, between the Santa Ana Mountains and the Perris Block structural provinces.

(3) Faults in the zone are known to displace late Pleistocene and Holocene age sediment.

(4) The Elsinore fault zone is seismically active and between 1932 and 1972 had more than sixty felt earthquakes. Five had Richter magnitudes of 4 or greater, ten of 3 or greater, and the remainder of 2 or greater.

(5) Microseismic study of the area shows that activity increases from approximately 0.5 events/day near Lake Elsinore to 3.5 events/day to the south along the zone near Mexico.

(6) The fault zone is composed of faults that have had complexly related lateral and vertical movements.

(7) Pleistocene strata is offset more than 5 km right laterally along one branch of the fault zone east of Wildomar.

(8) Miocene basalt is offset vertically more than 300 m along a branch of the fault located west of Wildomar.

(9) More than 1200 m of sediment underlie the Elsinore fault zone north of Temecula that owe their preservation and existence to vertical faulting.

(10) Faults juxtapose rocks in this area that range in age from middle Mesozoic to Holocene. Individual rock units have been assigned ages based on radiometric dating, fossil mammals, neutron activation analysis, and superposition.

(11) Most faults mapped are assigned ages based on the age of strata faulted. Several faults are known to be overlapped by late Pleistocene or Holocene sediments and are assigned an age indicating dormancy since that time.

(12) Each fault mapped is shown either as a solid line (known to exist) or as a dashed line (inferred from geologic or geomorphic data). The criteria used to infer a fault is given by symbol for each fault shown on plate 1.

(13) A thick succession of poorly consolidated alluvial fill underlies Murrieta, Pauba, and Wolf Valleys. These sediments when saturated by ground water have the potential to liquefy during a strong earthquake with a moderately long duration and a relatively high horizontal ground acceleration.

CONCLUSION

This study documents the previously suspected youthfulness of the Elsinore fault zone in that detailed mapping between Wildomar and upper Wolf Valley indicates that numerous individual faults in the zone displace Holocene sediments. Historic seismicity, though minor, indicates further that this part of the fault zone is presently active. In the event of a strong earthquake along this segment of the Elsinore fault zone, water–saturated sediments in valley areas could liquefy. Liquefaction of the near–surface sediments would likely result in ground failure.

REFERENCES CITED

Allen, C.R., St. Amand, Pierre, Richter, C.F., and Nordquist, J.M., 1965, Relationship between seismicity and geologic structure in the southern California region: Seismological Society of America Bulletin, v. 55, p. 753–797.

Biehler, Shawn, Kovach, R.L., and Allen, C.R., 1964, Geophysical framework of northern end of Gulf of California structural province, *in* van Andel, T.H., and Shor, G.G. Jr., editors, Marine geology of the Gulf of California: American Association of Petroleum Geologists Memoir 3, p. 126–143.

Clark, M.M., 1975, Character and distribution of recent movement along the southeastern part of the Elsinore fault zone, southern California [abstract]: Geological Society of America Abstracts with Programs, v. 7, no. 3, p. 304.

Dibblee, T.W. Jr., 1954, Geology of the Imperial Valley region, California, *in* Johns, R.H., editor, Geology of southern California: California Division of Mines Bulletin 170, chapter 2, p. 21–28.

Dietrich, W.F., 1928, The clay resources and the ceramic industry of California: California Division of Mines Bulletin 99, 383 p.

Engel, René, 1959, Geology of the Lake Elsinore quadrangle, California: California Division of Mines Bulletin 146, p. 1–59.

Evernden, J.F., and Kistler, R.W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Fairbanks, H.W., 1892, Geology of San Diego County; also of portions of Orange and San Bernardino Counties, *in* Yale, G.Y., editor, Eleventh report of the State Mineralogist: California State Mining Bureau Eleventh Report, p. 76–120.

Giessner, F.W., Winters, B.A., and McLean, J.S., 1971, Water wells and springs in the western part of the upper Santa Margarita River watershed, Riverside and San Diego Counties, California: California Department of Water Resources Bulletin 91–20, 377 p.

Golz, D.J., Jefferson, G.T., and Kennedy, M.P., 1977, Late Pliocene vertebrate fossils from the Elsinore fault zone, California: Journal of Paleontology, v. 51, p. 864–866.

Gray, C.H. Jr., 1961, Geology of the Corona South quadrangle and the Santa Ana Narrows area, Riverside, Orange, and San Bernardino Counties, California: California Division of Mines Bulletin 178, 120 p.

Hawkins, J.W., 1970, Petrology and possible tectonic significance of Late Cenozoic volcanic rocks, southern California and Baja California: Geological Society of America Bulletin, v. 81, no. 11, p. 3323–3338.

Hileman, J.A., Allen, C.R., and Nordquist, J.M., 1975, Seismicity of the southern California region 1 January 1932 to 31 December 1972: California Institute of Technology, Division of Geological and Planetary Sciences Contribution no. 2385.

Irwin, W.P., and Greene, R.C., 1970, Mineral resources of the Agua Tibia Primitive Area, California: U.S. Geological Survey Bulletin 1319–A, p. A1–A19.

Johns, R.H., 1954, Geology of the Peninsular Range Province, southern California and Baja California, *in* Johns, R.H., editor, Geology of southern California: California Division of Mines Bulletin 170, chapter 2, p. 29–52.

Jennings, C.W., 1975, Fault map of California with locations of volcanoes, thermal springs, and thermal wells: California Division of Mines and Geology Geologic Data Map 1.

Lajoie, K.R., and Helley, E.J., 1975, Differentiation of sedimentary deposits for purposes of seismic zonation, *in* Borcherdt, R.D., editor, Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941–A, p. A39–A51.

Longenkamp, David, and Combs, Jim, 1974, Microearthquake study of the Elsinore fault zone, southern California: Seismological Society of America Bulletin, v. 64, no. 1, p. 187–203.

Larsen, E.S., 1948, Batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangles, southern California: Geological Society of America Memoir 29, 182 p.

Lindsay, E.H., Johnson, N.M., and Opdyke, N.D., 1975, Preliminary correlation of North American land mammal ages and geomagnetic chronology: University of Michigan Papers on Paleontology, no. 12, p. 111–119.

Mann, J.F., 1955, Geology of a portion of the Elsinore fault zone, California: California Division of Mines Special Report 43, 22 p.

Merriam, R., and Bischoff, J.L., 1975, Bishop Ash: A widespread volcanic ash extended to southern California: Journal of Sedimentary Petrology, v. 45, p. 207–211.

Moreland, J.A., 1972, Maps of the watersheds of the Santa Margarita and San Luis Rey Rivers, Riverside and San Diego Counties, California: U.S. Geological Survey Open–File Maps.

Morton, D.M., and Baird, A.K., 1976, Petrology of the Paloma Valley ring complex, southern California batholith: U.S. Geological Survey Journal of Research, v. 4, p. 83–89.

Moyle, W.R., and Downing, D.J., 1975, Bouguer gravity anomaly map of the Temecula area, Riverside County, California: U.S. Geological Survey Open–File Map.

Richter, C.F., 1958, Elementary seismology: W.H. Freeman and Company, San Francisco, 768 p.

Rogers, T.H., 1965, Santa Ana sheet: California Division of Mines and Geology Geologic Map of California, scale 1:250,000.

Seed, H.B., and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: American Society of Civil Engineers, Journal of Soil Mechanics and Foundation Division, v. 97, p. 1249–1273.

Weber, F.H. Jr., 1963, Geology and mineral resources of San Diego County, California: California Division of Mines and Geology County Report 3, 309 p.

Weber, F.H. Jr., 1975, Character and recency of movement along the Elsinore and Chino fault zones in Riverside County, California: Geological Society of America Abstracts with Programs, v. 7, no. 3, p. 386.

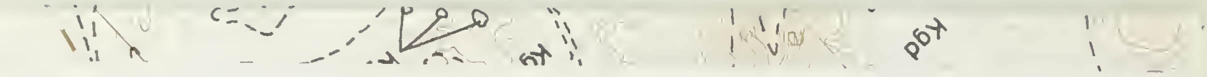
Weber, F.H. Jr., 1976, Preliminary map of faults of the Elsinore and Chino fault zones in northeastern Riverside County, California, showing accompanying features related to character and recency of movement: California Division of Mines and Geology Open–File Report 76–1 LA.

Woodford, A.O., Shelton, F.S., Doehring, D.O., and Morton, R.K., 1971, Pliocene–Pleistocene history of the Perris Block, southern California: Geological Society of America Bulletin, v. 82, no. 12, p. 3421–3448.

Youd, T.L., 1973, Liquefaction, flow, and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T.L., Nichols, D.R., Helley, E.J., and Lajoie, K.R., 1975, Liquefaction potential, *in* Borcherdt, R.D., editor, Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941–A, p. A68–A74.

Ziony, J.I., Wentworth, C.M., Buchanan, J.M., and Wagner, H.C., 1974, Preliminary map showing recency of faulting in coastal southern California: U.S. Geological Survey Miscellaneous Field Studies Map MF–585.



PHYSICAL SCIENCES LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616

PHYSICAL SCIENCES LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616

CALIFORNIA DIVISION OF MINES AND GEOLOGY
THOMAS E. GAY JR., STATE GEOLOGIST

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

LEGEND

QUATERNARY

Holocene

Qal
Alluvium, colluvium, and slope wash

Qoal
Older alluvium

Qtr
Stream-terrace deposits

Qt
Terrace deposits

Qls
Landslide deposits

Pleistocene

Qds
Dripping Springs Formation

Qps / Qpf
Pauba Formation
Qps, sandstone part; Qpf, fanglomerate part.

Qus / Quc
Unnamed sandstone and conglomerate, formation
Qus, sandstone part; Quc, conglomerate part.

TERTIARY

Pliocene

Tta
Temecula Arkose

Miocene

Tsr
Santa Rosa Basalt

Tot
Older terrace deposits

CRETACEOUS

Kqm | Kqmd
Quartz monzonite
Kqm, fresh rock; Kqmd, decomposed rock.

Kgd
Granodiorite

Kgb
Gabbro and quartz bearing gabbro

Kgp
Granophyre

Kh
Hybrid rocks
Mixed gabbro, granodiorite and low-grade metamorphic rocks.

PRE-CRETACEOUS

Jm
Metamorphic rocks of the Bedford Canyon Formation and Santiago Peak Volcanics

MAP SYMBOLS

U
O
75
FAULT

Solid line where confirmed, dashed line where inferred, dotted line where concealed by unfaulted rocks; U, upthrown side; O, downdropped side; single arrow and corresponding number indicate direction and amount of dip of fault plane; double arrows indicate the relative direction of horizontal movement; ~~~ indicates shear zone; X, indicates fault based on gravity data.

Geologic contact

Syncline

Anticline

Dike in metamorphic rock complex

Tuffaceous horizon

Conglomerate horizon in sandstone formation

15
Dip and strike of bedding

30
Dip and strike of overturned bedding

15
Approximate dip and strike of bedding

40
Strike and dip of layering in volcanic rocks

75
Strike and dip of S-surface in metamorphic rocks

50
Dip and strike of joint

Strike of vertical joint

● 05 20 75 01
Rock sample locality

● 05 15 75 01 (KA 9)
Rock sample locality of material dated by K/Ar analysis.

Berghofer No. 1 (1234 m)
Exploratory oil well showing total depth drilled below land surface and name.

○ 8S 2W 17 H1
Water well showing State number.

cd
Closed depression

Qls (5d)
Landslide deposit and corresponding number.

75
Contours of the ground water table as measured in the autumn of 1971. (Contour interval in 25 m).

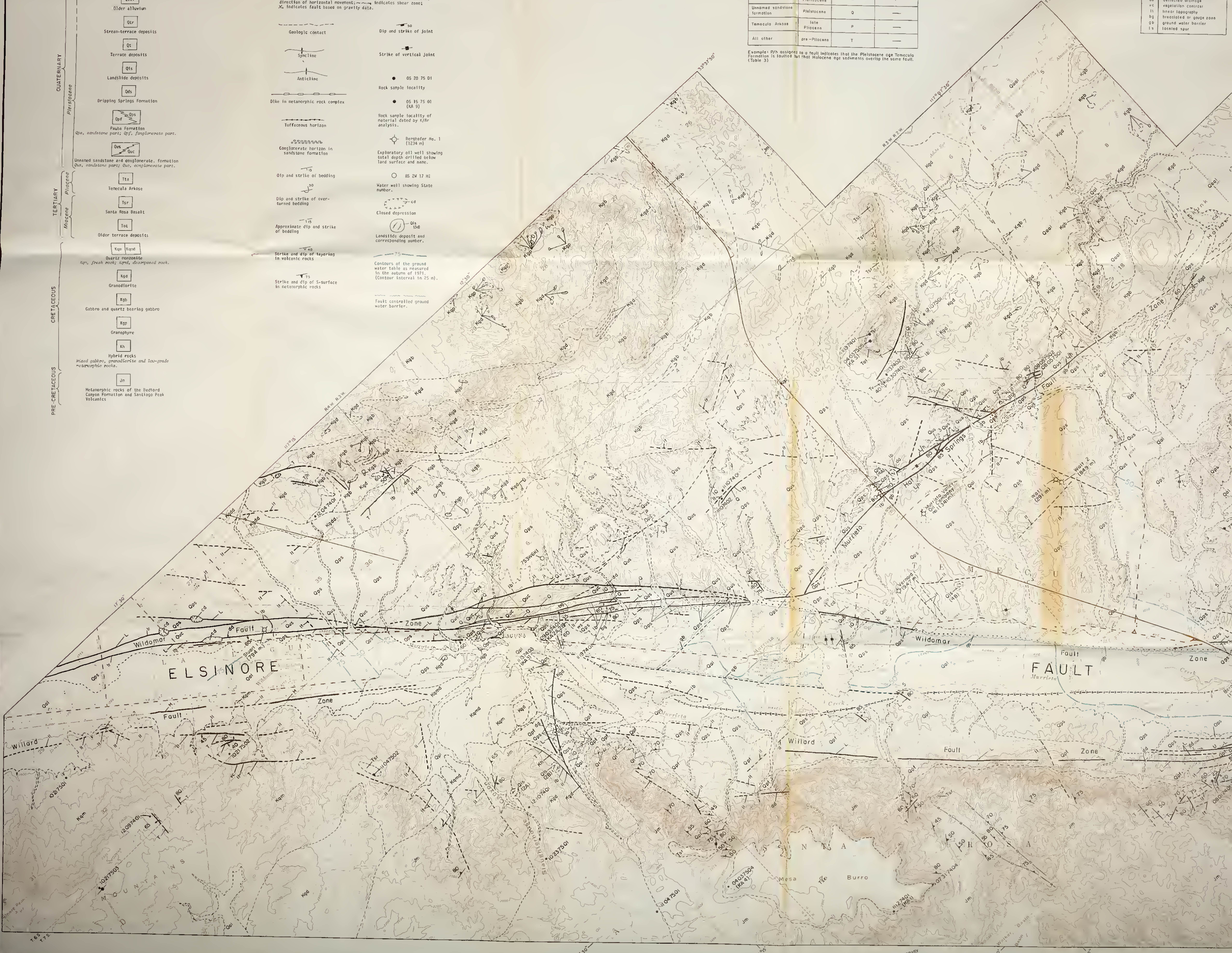
Fault controlled ground water barrier.

KEY TO AGE OF FAULTS			
FORMATION	AGE	SYMBOL IF FAULTED	SYMBOL IF NOT FAULTED
Alluvium, colluvium and slope wash	Holocene	H	h
Pauba Formation	late Pleistocene	L	l
Unnamed sandstone formation	Pleistocene	Q	—
Temecula Arkose	late Pliocene	P	—
All other	pre-Pliocene	T	—

Example: P/h assigned to a fault indicates that the Pleistocene age Temecula Formation is faulted but that Holocene age sediments overlap the same fault. (Table 3)

KEY TO ABBREVIATIONS USED FOR SURFICIAL FAULT FEATURES	
lr	linear ridge
pa	ponded alluvium
lb	lithologic boundary
cd	closed depression
dd	deflected drainage
vc	vegetation contrast
lt	linear topography
bg	brecciated or gouge zone
gb	ground water barrier
fs	faceted spur

PHYSICAL SCIENCES LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616



TOPOGRAPHIC MAP BASE BY U.S GEOLOGICAL SURVEY

PHYSICAL SCIENCES LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616

RESEARCH SPONSORED BY THE UNITED STATES GEOLOGICAL SURVEY,
DEPT. OF THE INTERIOR, UNDER U.S.G.S. GRANT NO. 14-08-0001-G-133,263

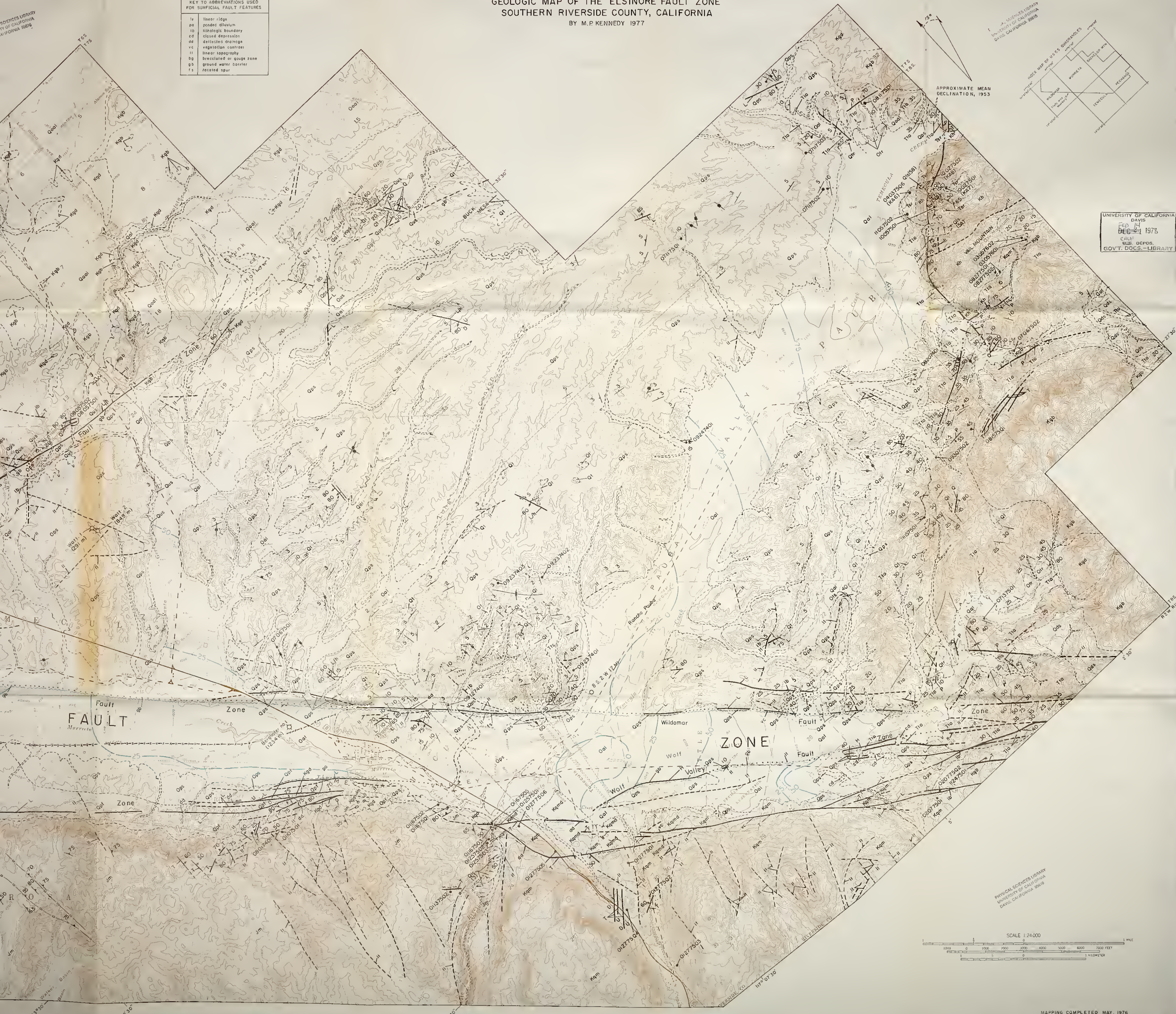
LIBRARY UNIVERSITY OF CALIFORNIA DAVIS

GEOLOGIC MAP OF THE ELSINORE FAULT ZONE
SOUTHERN RIVERSIDE COUNTY, CALIFORNIA

BY M.P. KENNEDY 1977

KEY TO ABBREVIATIONS USED FOR SURFICIAL FAULT FEATURES

lr	linear ridge
pa	ponded alluvium
lb	lithologic boundary
cd	closed depression
dd	deflected drainage
vc	vegetation contrast
ll	linear topography
bg	brecciated or gouge zone
gb	ground water barrier
fs	faceted spur



PHYSICAL SCIENCES LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616

UNIVERSITY OF CALIFORNIA
DAVIS
FEB 14
~~DEC 21~~ 1978
CALIF
DEPOS.
GOV'T. DOCS.-LIBRARY

SCALE 1:24000

MAPPING COMPLETED MAY, 1976

NOTE: Geologic mapping of the ring dike complex in the northern part of the area modified from Morton and Baird (1976), and unpublished mapping by D.M. Morton (written communications).

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

BOOKS REQUESTED BY ANOTHER BORROWER
ARE SUBJECT TO RECALL AFTER ONE WEEK.
RENEWED BOOKS ARE SUBJECT TO
IMMEDIATE RECALL

JUN 25 1982

REC'D
NOV - 6 1981
PHYS SCI LIBRARY

OCT 12 1991

MAR 30 1999

RECEIVED
MAR 26 1999
PSL

LIBRARY, UNIVERSITY OF CALIFORNIA, DAVIS
D4613 (12/76)

PHYSICAL SCIENCES LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616

3 1175 00656 1263

TN
24
C3
A33
no.131

California. Division of Mines and Gelogy.
Special report.

COLLATE
(1 map)

PHYSICAL
SCIENCES
LIBRARY

G A M NOV 17 '78 [illegible]